Prevention of incisional hernia after midline laparotomy with prophylactic mesh reinforcement: a meta-analysis and trial sequential analysis

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Background: Incisional hernia is a frequent complication after abdominal surgery. The aim of this study was to assess the efficacy of prophylactic mesh reinforcement (PMR) after midline laparotomy in reducing the incidence of incisional hernia.

Methods: A meta-analysis was conducted following PRISMA guidelines. The primary outcome was the incidence of incisional hernia after follow-up of at least 12 months. Secondary outcomes were postoperative complications. Only RCTs were included. A random-effects model was used for the meta-analysis, and trial sequential analysis was conducted.

Results: Twelve RCTs were included, comprising 1815 patients. The incidence of incisional hernia was significantly lower after PMR compared with sutured closure (risk ratio (RR) 0·35, 95 per cent c.i. 0·21 to 0·57; $P < 0.001$). Both onlay (RR 0·26, 0·11 to 0·67; $P = 0.005$) and retromuscular (RR 0·28, 0·10 to 0·82; $P = 0.02$) PMR led to a significant reduction in the rate of incisional hernia. The occurrence of seroma was higher in patients who had onlay PMR (RR 2·23, 1·10 to 4·52; $P = 0.03$). PMR did not result in an increased rate of surgical-site infection.

Conclusion: PMR of a midline laparotomy using an onlay or retromuscular technique leads to a significant reduction in the rate of incisional hernia in high-risk patients. Individual risk factors should be taken into account to select patients who will benefit most.

[Correction added on 19 February 2020, after first online publication: J. García Alamino has been amended to J. M. Garcia-Alamino]

Introduction

Incisional hernia (IH) is a frequent complication after abdominal surgery, with an incidence ranging from 11 to 20 per cent in general surgical populations[1−4]. The incidence of IH can increase up to 40 per cent in high-risk groups, such as patients with an abdominal aortic aneurysm (AAA) or morbid obesity[5−12]. IH may be asymptomatic, but can also lead to serious and potentially fatal complications, such as incarceration and strangulation of bowel. Furthermore, IH has a high impact on patients' quality of life and body image[13,14], and treatment of IH represents a financial burden on the healthcare system[15].

Current treatment of IH is mesh repair, which has led to a lower recurrence rate compared with the primary suture technique[16]. However, the recurrence rate is still high, even when mesh is used. A Danish nationwide registry study[17] reported a cumulative recurrence rate of 37 per cent at 3 years after IH repair. Currently, there is no definitive solution for the high recurrence rates and complications related to these recurrences. Prevention is therefore of paramount importance[18]. In the past

Fig. 1 PRISMA diagram for the review
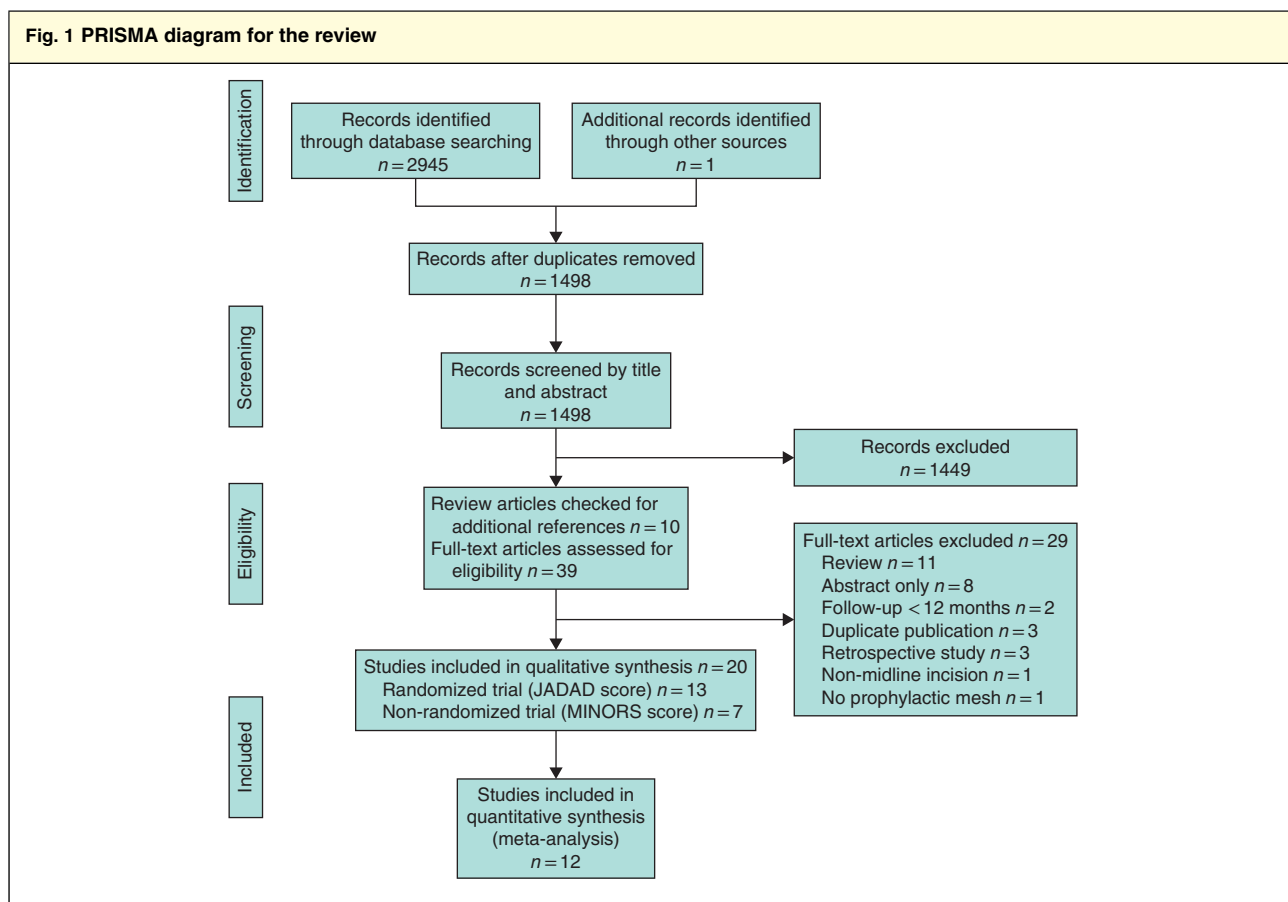
Table 1 Risk-of-bias assessment for prevention of incisional hernia with prophylactic mesh reinforcement in midline laparotomy

Reference	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)
Abo-Ryia et al.[9]	−	−	−	−		+
Bali et al.[10]	−	−	−	−	+	+
Bevis et al.[8]	+	+	+	+	+	+
Caro-Tarrago et al.[29]	+		+	+		+
El-Khadrawy et al.[28]	−	−	−	−		+
García-Ureña et al.[31]	+		+	+	+	+
Gutiérrez de la Peña et al.[6]	−	−	−	−		+
Jairam et al.[23]	+	+	+	+		+
Muysoms et al.[11]	+	+	+	+		+
Pans et al.[5]	−	−	−	−		+
Sarr et al.[30]	+	−	−	−	−	+
Strzelczyk et al.[7]	+		+	+		+

+, Low risk of bias; −, high risk of bias.

Table 2 Summary of findings for included studies on the prevention of incisional hernia with prophylactic mesh reinforcement in midline laparotomies

Reference	n	Indication for midline laparotomy	Type of mesh	Mesh position	Follow-up (months)	Outcome measurements	Diagnosis of IH (clinical/radiological)
Pans et al.[5]	288	Morbid obesity	Polyglactin	Intraperitoneal	29·8	IH, postoperative morbidity	Not reported
Gutiérrez de la Peña et al.[6]	88	Colorectal cancer, gastric cancer, cholelithiasis, diverticulosis, Crohn's disease, pancreatic cystadenoma, gastric ulcer, cancer of small intestine	Polypropylene	Onlay	36	IH, haematoma, seroma, infection, pain	Clinical; if not conclusive, CT
Strzelczyk et al.[7]	74	Gastric bypass surgery	Polypropylene	Retromuscular	28	IH, wound leak, bleeding, other surgical complication	Clinical plus ultrasound imaging
El-Khadrawy et al.[28]	40	High risk	Polypropylene	Preperitoneal	36·7	IH, seroma	Clinical
						SSI, wound disruption, chronic wound pain, cardiac, pulmonary problems, DVT, ascites	
Bevis et al.[8]	80	AAA	Polypropylene	Retromuscular	Mesh 30·2	IH, wound infection, hernia operation	Clinical; if doubt, ultrasound imaging
					No mesh 19·6		
Abo-Ryia et al.[9]	64	Open bariatric surgery	Polypropylene	Preperitoneal	Mesh 48	Safety and efficacy of preperitoneal prosthetic enforcement, seroma, infection, partial dehiscence	Clinical; ultrasound imaging in suspected cases
					No mesh 49		
Caro-Tarrago et al.[29]	160	Colorectal and general surgery	Polypropylene	Onlay	Mesh 14·8	IH, all adverse events, postoperative complications	Clinical and CT
					No mesh 12·5		
Sarr et al.[30]	280	Open RYGB	Biological	Intraperitoneal	24	IH, wound infection, wound dehiscence, wound sinus tract, wound erythema, seroma	Clinical, phone call, primary care physician
Bali et al.[10]	40	Open AAA	Biological	Onlay	36	IH, duration of surgery, postoperative complications, reoperation rate	Clinical and CT
García-Ureña et al.[31]	107	Colorectal surgery	Polypropylene	Onlay	24	IH, incidence of local complications: SSI, seroma, evisceration, mesh rejection	Clinical and CT
						Systemic complications	
Muysoms et al.[11]	114	AAA and ASA grade < IV	Partially absorbable polypropylene	Retromuscular	24	IH	Clinical and, if available, ultrasound imaging or CT
						Postoperative complications	
						SSI	
						Duration of surgery	
Jairam et al.[23]	480	Open AAA surgery or midline laparotomy in patients with BMI > 27 kg/m^2	Polypropylene	Onlay (188 patients)	24	IH, postoperative complications	Clinical and ultrasound imaging or CT
						Quality of life	
						Cost-effectiveness	
				Retromuscular (185 patients)			

IH, incisional hernia; SSI, surgical-site infection; DVT, deep vein thrombosis; AAA, abdominal aortic aneurysm; RYGB, Roux-en-Y gastric banding.

few years, several studies on the prevention of IH with prophylactic mesh reinforcement (PMR) have been conducted. Most RCTs included a limited number of patients. Different surgical techniques of PMR, including mesh placement in onlay, retromuscular or intraperitoneal position, have been studied. The European Hernia Society (EHS) Guidelines Development Group[19] on the closure of abdominal wall incisions made a recommendation in

2015: that PMR to reduce the incidence of IH after elective midline laparotomy in a high-risk patient be suggested with a weak recommendation. The group also stated that larger trials were needed to make a strong recommendation.

Since the publication of these EHS guidelines, three meta-analyses[20–22] have been published, together with the long-term data from the largest multicentre RCT on

Fig. 2 Forest plots of incisional hernia after prophylactic mesh reinforcement of a midline laparotomy *versus* primary suture

a   Overall data

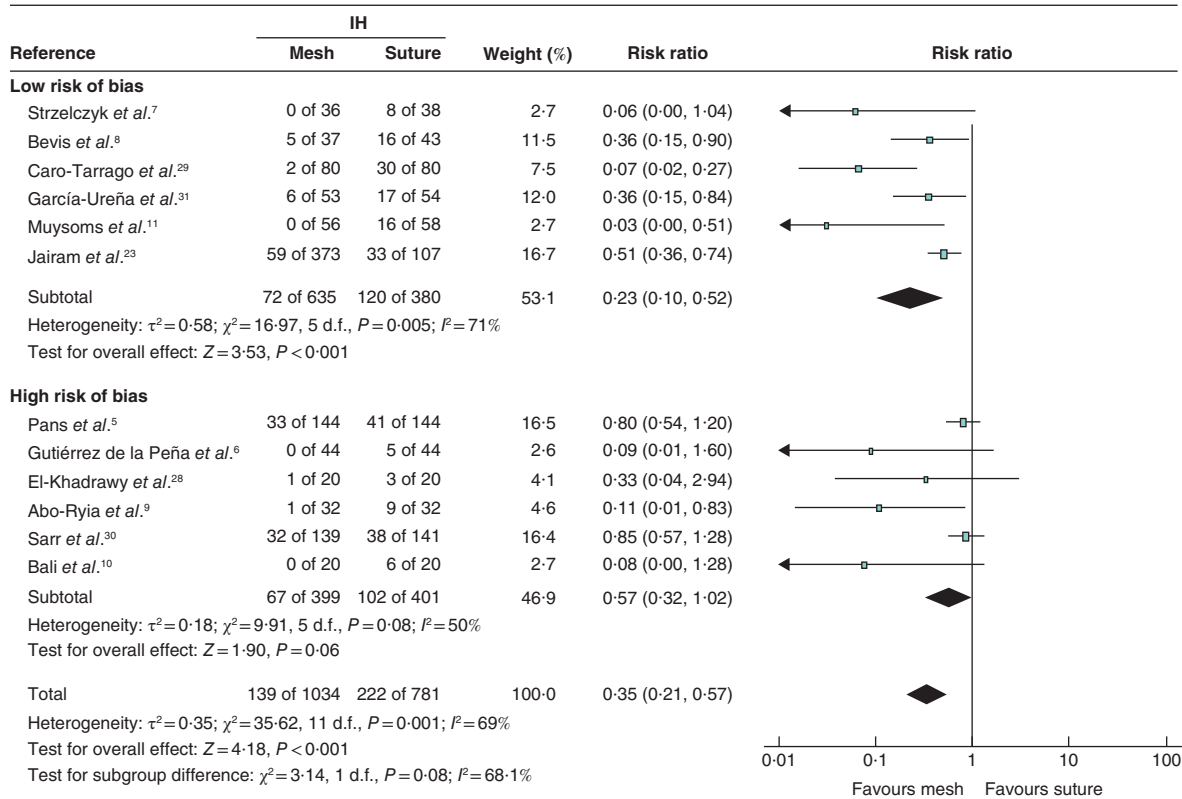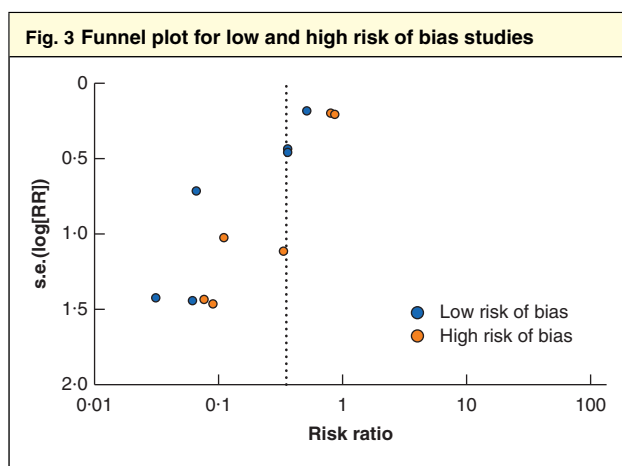| Reference	IH		Weight (%)	Risk ratio	Risk ratio
	Mesh	Suture			
Pans *et al.*[5]	33 of 144	41 of 144	16·5	0·80 (0·54, 1·20)	
Gutiérrez de la Peña *et al.*[6]	0 of 44	5 of 44	2·6	0·09 (0·01, 1·60)	
Strzelczyk *et al.*[7]	0 of 36	8 of 38	2·7	0·06 (0·00, 1·04)	
El-Khadrawy *et al.*[28]	1 of 20	3 of 20	4·1	0·33 (0·04, 2·94)	
Bevis *et al.*[8]	5 of 37	16 of 43	11·5	0·36 (0·15, 0·90)	
Abo-Ryia *et al.*[9]	1 of 32	9 of 32	4·6	0·11 (0·01, 0·83)	
Sarr *et al.*[30]	32 of 139	38 of 141	16·4	0·85 (0·57, 1·28)	
Caro-Tarrago *et al.*[29]	2 of 80	30 of 80	7·5	0·07 (0·02, 0·27)	
Bali *et al.*[10]	0 of 20	6 of 20	2·7	0·08 (0·00, 1·28)	
García-Ureña *et al.*[31]	6 of 53	17 of 54	12·0	0·36 (0·15, 0·84)	
Muysoms *et al.*[11]	0 of 56	16 of 58	2·7	0·03 (0·00, 0·51)	
Jairam *et al.*[23]	59 of 373	33 of 107	16·7	0·51 (0·36, 0·74)	
Total	**139 of 1034**	**222 of 781**	**100·0**	**0·35 (0·21, 0·57)**	

Heterogeneity: $\tau^2 = 0.35$; $\chi^2 = 35.62$, 11 d.f., $P < 0.001$; $I^2 = 69\%$
Test for overall effect: $Z = 4.18$, $P < 0.001$

Favours mesh   Favours suture

b   According to risk of bias

Reference	IH		Weight (%)	Risk ratio	Risk ratio
	Mesh	Suture			
Low risk of bias					
Strzelczyk *et al.*[7]	0 of 36	8 of 38	2·7	0·06 (0·00, 1·04)	
Bevis *et al.*[8]	5 of 37	16 of 43	11·5	0·36 (0·15, 0·90)	
Caro-Tarrago *et al.*[29]	2 of 80	30 of 80	7·5	0·07 (0·02, 0·27)	
García-Ureña *et al.*[31]	6 of 53	17 of 54	12·0	0·36 (0·15, 0·84)	
Muysoms *et al.*[11]	0 of 56	16 of 58	2·7	0·03 (0·00, 0·51)	
Jairam *et al.*[23]	59 of 373	33 of 107	16·7	0·51 (0·36, 0·74)	
Subtotal	**72 of 635**	**120 of 380**	**53·1**	**0·23 (0·10, 0·52)**	

Heterogeneity: $\tau^2 = 0.58$; $\chi^2 = 16.97$, 5 d.f., $P = 0.005$; $I^2 = 71\%$
Test for overall effect: $Z = 3.53$, $P < 0.001$

High risk of bias					
Pans *et al.*[5]	33 of 144	41 of 144	16·5	0·80 (0·54, 1·20)	
Gutiérrez de la Peña *et al.*[6]	0 of 44	5 of 44	2·6	0·09 (0·01, 1·60)	
El-Khadrawy *et al.*[28]	1 of 20	3 of 20	4·1	0·33 (0·04, 2·94)	
Abo-Ryia *et al.*[9]	1 of 32	9 of 32	4·6	0·11 (0·01, 0·83)	
Sarr *et al.*[30]	32 of 139	38 of 141	16·4	0·85 (0·57, 1·28)	
Bali *et al.*[10]	0 of 20	6 of 20	2·7	0·08 (0·00, 1·28)	
Subtotal	**67 of 399**	**102 of 401**	**46·9**	**0·57 (0·32, 1·02)**	

Heterogeneity: $\tau^2 = 0.18$; $\chi^2 = 9.91$, 5 d.f., $P = 0.08$; $I^2 = 50\%$
Test for overall effect: $Z = 1.90$, $P = 0.06$

Total	**139 of 1034**	**222 of 781**	**100·0**	**0·35 (0·21, 0·57)**	

Heterogeneity: $\tau^2 = 0.35$; $\chi^2 = 35.62$, 11 d.f., $P = 0.001$; $I^2 = 69\%$
Test for overall effect: $Z = 4.18$, $P < 0.001$
Test for subgroup difference: $\chi^2 = 3.14$, 1 d.f., $P = 0.08$; $I^2 = 68.1\%$

Favours mesh   Favours suture

a Overall data from all 12 included studies; **b** data for studies with a low or high risk of bias. A Mantel–Haenszel random-effects model was used for meta-analysis. Risk ratios are shown with 95 per cent confidence intervals. IH, incisional hernia.

Fig. 3 Funnel plot for low and high risk of bias studies

RR, risk ratio.

IH prevention after midline laparotomy, comparing PMR with primary suture (the PRIMA trial)[23]. However, in one of these meta-analyses[20], RCTs and observational studies were mixed. In the meta-analysis of Wang and colleagues[21], some studies on non-midline incisions were included and none of the meta-analyses included long-term data from the PRIMA trial.

The aim of this meta-analysis was to assess the safety and efficacy of PMR, both onlay and retromuscular, in reducing the IH incidence after elective midline laparotomy.

Methods

A meta-analysis was conducted and reported following the PRISMA guidelines[24]. This meta-analysis was registered prospectively at the Prospero database on 5 November 2015 (CRD42015027079) with the acronym MARIA review. The meta-analysis was finalized after publication of the final results of the PRIMA trial on 19 June 2017.

Information sources and search terms

A systematic computerized literature search was performed until 1 January 2017, using 12 databases: Embase, MEDLINE, Web of Science, SCOPUS, Cochrane Library, CINAHL, PubMed Publisher, LILACS (Latin American and Caribbean Literature on Health Sciences), SciELO (Scientific Electronic Library Online), ScienceDirect, ProQuest and Google Scholar. The Biomedical Information Specialist of the Medical Library (Erasmus University Medical Centre, Rotterdam, the Netherlands) prepared the search strategy. The syntax with search terms is shown in *Appendix S1* (supporting information).

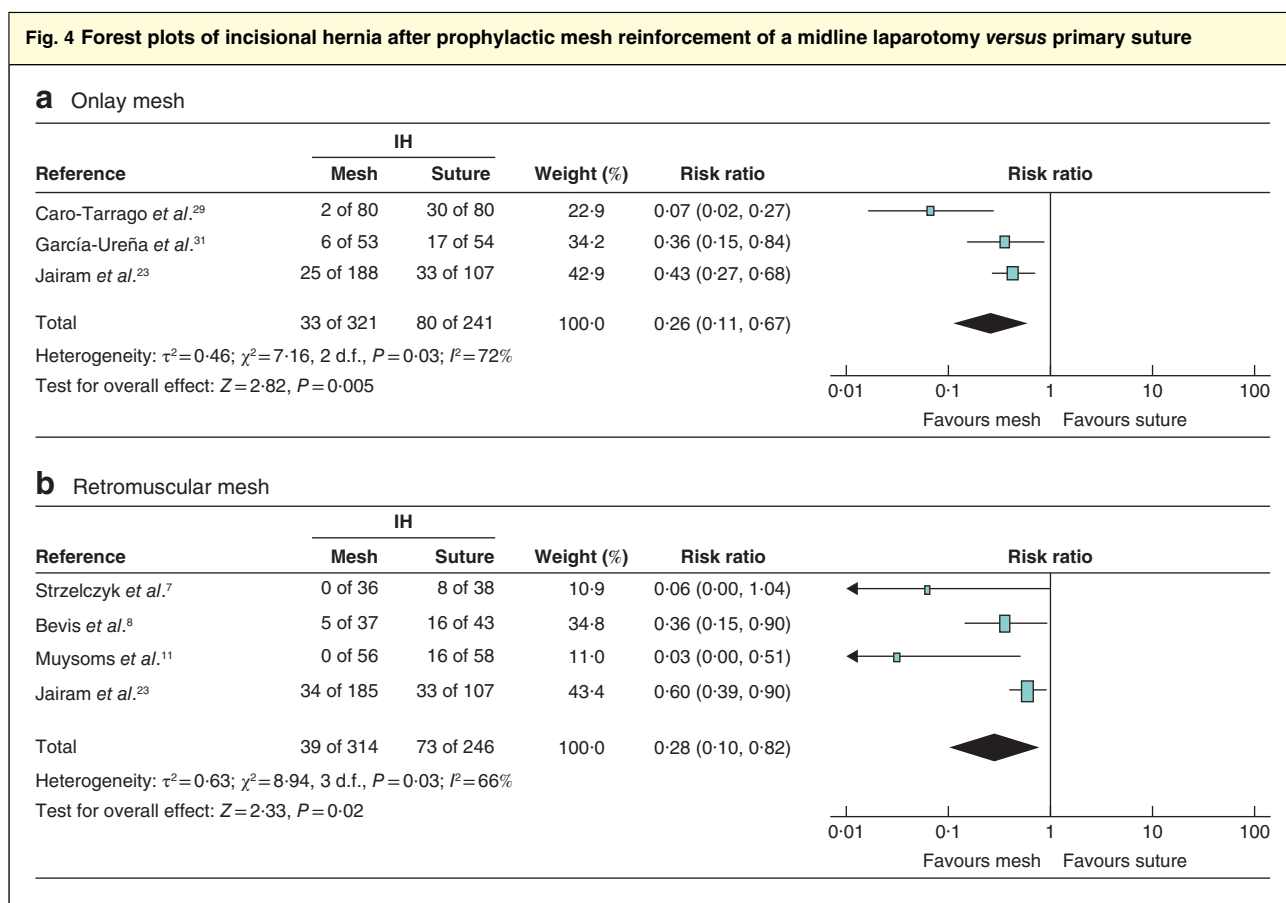### Study selection, data extraction and quality assessment

Three reviewers independently screened all records by title and abstract for eligibility. After this first screening, the full text of records was assessed. Only eligible RCTs were included. The methodological quality of RCTs was assessed using SIGN (Scottish Intercollegiate Guidelines Network) checklists. Risk-of-bias assessment was done with the Cochrane Collaboration tool[25], in which the following aspects are assessed: random sequence generation, allocation concealment, blinding of patients, personnel or outcome assessors, incomplete outcome data and selective reporting. Assessment of both methodological quality and risk of bias was performed by three independent reviewers. Studies were assessed as having either a low or high risk of bias.

RCTs were included if they met the following inclusion criteria: patients aged at least 18 years, undergoing midline laparotomy, for all types of indication, with all types of mesh and all types of mesh position, and follow-up of at least 12 months. The primary outcome was the incidence of IH. Secondary outcomes were postoperative complications: seroma, surgical-site infection (SSI), haematoma and burst abdomen. No language restrictions were used.

All required data were extracted and collected in a standard manner by at least two authors independently. Any disagreements during the data extraction phase were resolved through discussion and by consulting a third investigator. A summary-of-findings table was created, in which the following information was collected: study characteristics (title, year of publication, study design, number of included patients), indication for midline laparotomy, description of intervention and description of the compared intervention ('control group'), type of mesh used, mesh placement, length of follow-up and outcome measurements. When a paper included data for different mesh positions, the data for these were described separately per group in the summary-of-findings table. For duplicate data reported by the same author(s), the article with the longest follow-up period was selected.

Statistical analysis

A meta-analysis, pooling the results of the retrieved studies, was performed. A sensitivity analysis was conducted to reduce the risk of possible bias for primary and secondary outcomes. Meta-analyses that combined other subgroups (mesh position) were also performed. A random-effects model was used and presented as risk ratios (RRs) with 95 per cent confidence intervals. Effects were considered statistically significant if the 95 per cent c.i. of the

Fig. 4 **Forest plots of incisional hernia after prophylactic mesh reinforcement of a midline laparotomy *versus* primary suture**

a Onlay mesh

| Reference | IH | | Weight (%) | Risk ratio | Risk ratio |
	Mesh	Suture			
Caro-Tarrago et al.[29]	2 of 80	30 of 80	22·9	0·07 (0·02, 0·27)	
García-Ureña et al.[31]	6 of 53	17 of 54	34·2	0·36 (0·15, 0·84)	
Jairam et al.[23]	25 of 188	33 of 107	42·9	0·43 (0·27, 0·68)	
Total	33 of 321	80 of 241	100·0	0·26 (0·11, 0·67)	

Heterogeneity: $\tau^2 = 0.46$; $\chi^2 = 7.16$, 2 d.f., $P = 0.03$; $I^2 = 72\%$
Test for overall effect: $Z = 2.82$, $P = 0.005$

0·01   0·1   1   10   100
Favours mesh   Favours suture

b Retromuscular mesh

| Reference | IH | | Weight (%) | Risk ratio | Risk ratio |
	Mesh	Suture			
Strzelczyk et al.[7]	0 of 36	8 of 38	10·9	0·06 (0·00, 1·04)	
Bevis et al.[8]	5 of 37	16 of 43	34·8	0·36 (0·15, 0·90)	
Muysoms et al.[11]	0 of 56	16 of 58	11·0	0·03 (0·00, 0·51)	
Jairam et al.[23]	34 of 185	33 of 107	43·4	0·60 (0·39, 0·90)	
Total	39 of 314	73 of 246	100·0	0·28 (0·10, 0·82)	

Heterogeneity: $\tau^2 = 0.63$; $\chi^2 = 8.94$, 3 d.f., $P = 0.03$; $I^2 = 66\%$
Test for overall effect: $Z = 2.33$, $P = 0.02$

0·01   0·1   1   10   100
Favours mesh   Favours suture

a Data from studies using onlay mesh reinforcement; **b** data from studies using retromuscular mesh reinforcement. A Mantel–Haenszel random-effects model was used for meta-analysis. Risk ratios are shown with 95 per cent confidence intervals. IH, incisional hernia.

overall effect estimate did not overlap. The I^2 statistic was used to assess heterogeneity. Groups with zero events were adjusted with a constant continuity adjustment of 0·5 in each arm (as per the default adjustment in the software used). Publication bias was assessed by a funnel plot. Analyses were performed using Review Manager software (RevMan version 5.3; The Nordic Cochrane Centre, Copenhagen, Denmark). Two-sided $P < 0.050$ was considered statistically significant.

Conducting a meta-analysis can lead to type I errors (false-positives) or overestimation of treatment effects due to systematic errors (bias) and random errors (play of change). To avoid this, trial sequential analysis (TSA) was conducted. TSA can provide a required information size (RIS). The RIS is the required number of patients that needs to be included in the meta-analysis to provide firm evidence[26,27]. Control event rate (CER) and relative risk reduction (RRR) values were calculated. CER is the proportion of participants in the control group who have the outcome. RRR can be interpreted as the reduction in the

relative risk of the specified outcome in the treatment group, compared with the control group. TSA was planned for all retrieved studies, and for the group of studies with low risk of bias. TSA was performed using the TSA software v0.9 (http://www.ctu.dk/tsa/downloads.aspx).

Results

A total of 1498 records were identified after removal of duplicates. After screening of title and abstract, 49 articles were found relevant for full-text assessment. After full-text assessment, 29 articles were excluded, leaving 13 RCTs and seven non-randomized trials for the qualitative synthesis (*Fig. 1*). In total, 13 RCTs[5–11,23,28–32] fulfilled the inclusion criteria, but the study of Timmermans and colleagues[32] was excluded because only the short-term results (postoperative complications in the first month) were discussed; thus 12 RCTs were analysed. Six studies[7,8,11,23,29,31] were considered to have a low risk of bias, and six[5,6,9,10,28,30] to have a high risk of bias (*Table 1*).

Fig. 5 Trial sequential analysis curves of the incidence of incisional hernia after prophylactic mesh reinforcement of a midline laparotomy *versus* primary suture

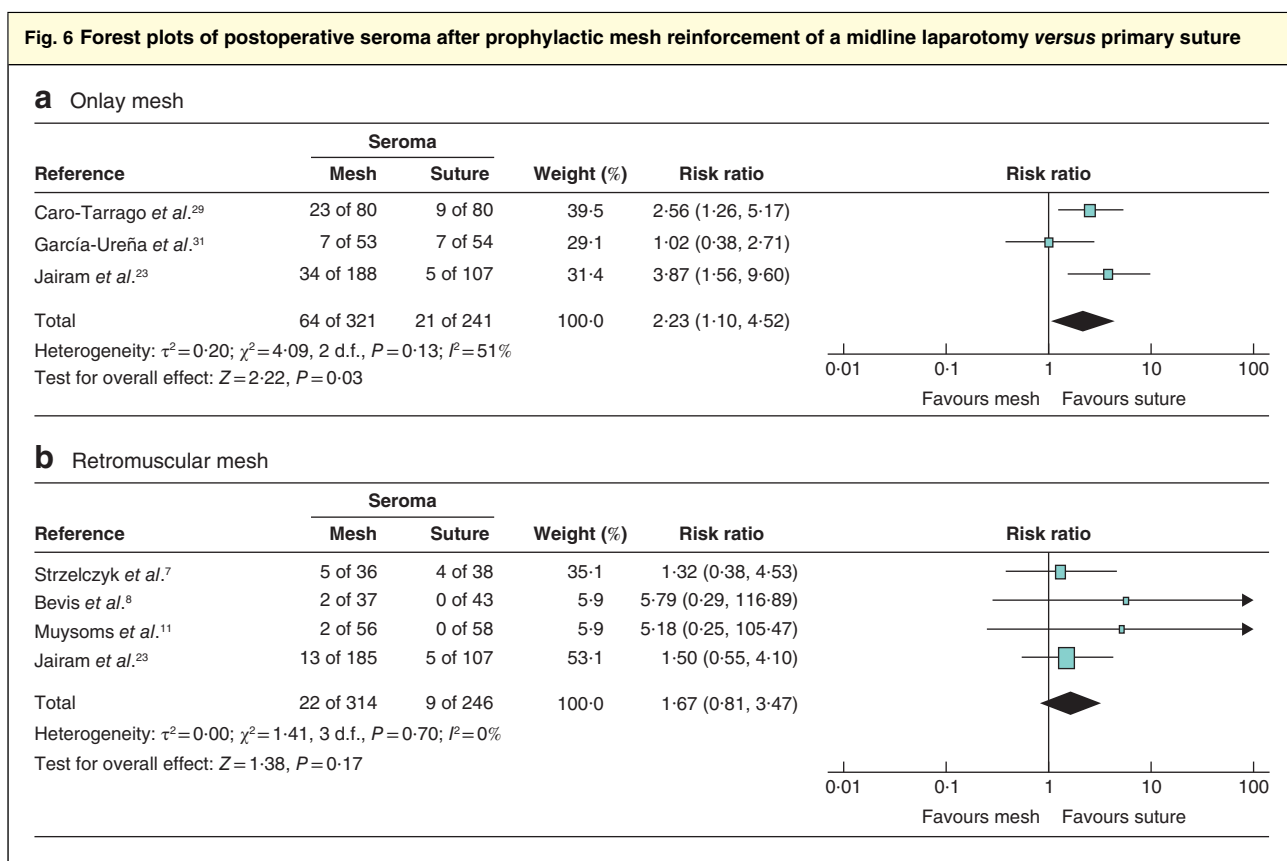**a** Overall data

b Low-risk-of-bias data
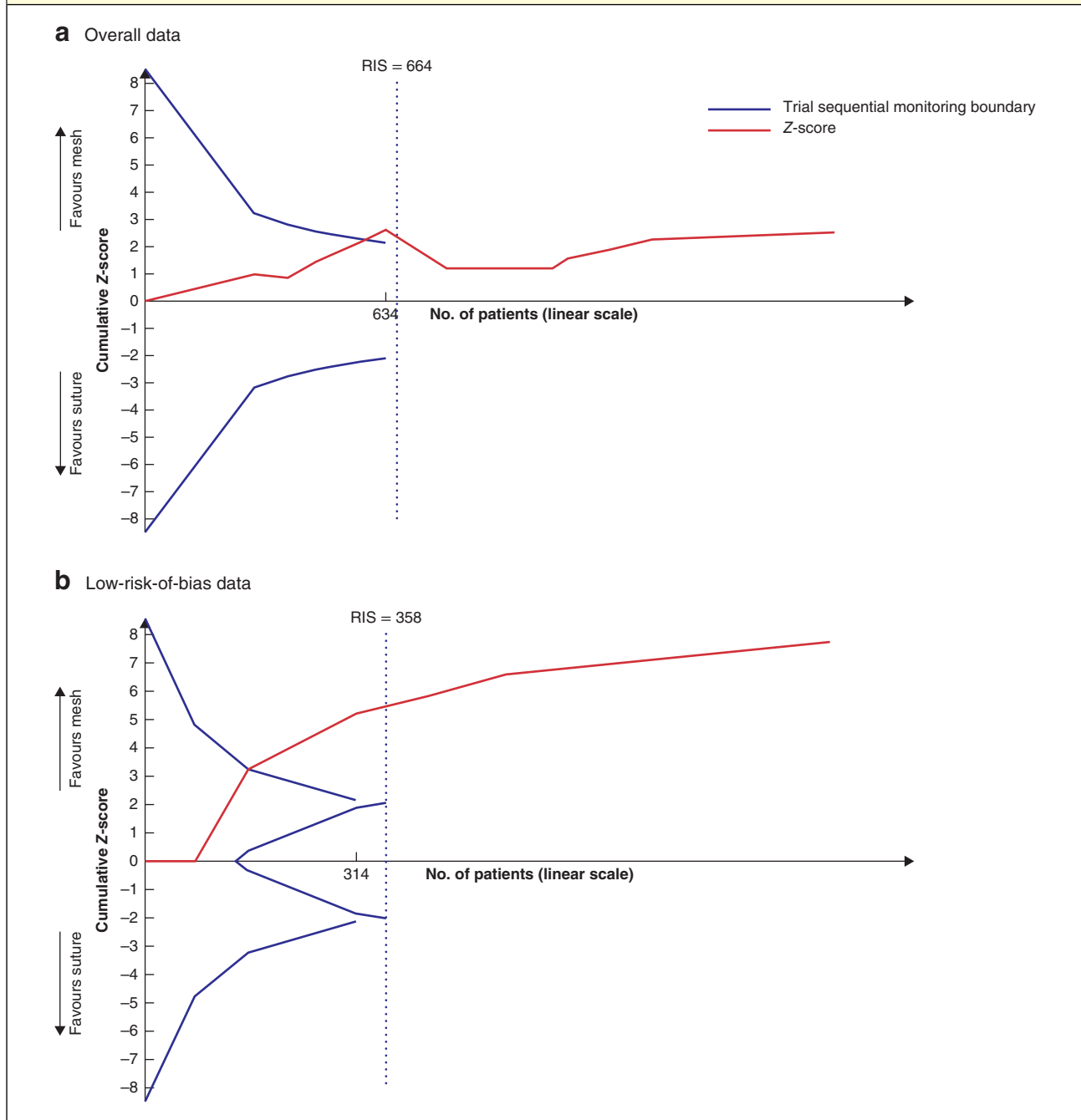
a Overall data from all 12 included studies; **b** data from studies with a low risk of bias. **a,b** Both graphs are two-sided. RIS, required information size.

The 12 RCTs comprised a total of 1815 patients. Study and patient characteristics are shown in *Table 2*. Inclusion criteria for PMR of the midline laparotomy in the individual RCTs were either the presence of an AAA[8,10,11,23], morbid obesity[5,7,9,30], colorectal cancer surgery[31] or a mixture of operative indications[6,28,29]. Most studies placed a polypropylene mesh in an onlay[6,10,23,29,31] or retromuscular[7,8,11,23] position. Two studies[10,30] used

Fig. 6 Forest plots of postoperative seroma after prophylactic mesh reinforcement of a midline laparotomy *versus* primary suture

a Onlay mesh

| Reference | Seroma | | Weight (%) | Risk ratio |
	Mesh	Suture		
Caro-Tarrago *et al.*[29]	23 of 80	9 of 80	39·5	2·56 (1·26, 5·17)
García-Ureña *et al.*[31]	7 of 53	7 of 54	29·1	1·02 (0·38, 2·71)
Jairam *et al.*[23]	34 of 188	5 of 107	31·4	3·87 (1·56, 9·60)
Total	64 of 321	21 of 241	100·0	2·23 (1·10, 4·52)

Heterogeneity: $\tau^2 = 0.20$; $\chi^2 = 4.09$, 2 d.f., $P = 0.13$; $I^2 = 51\%$
Test for overall effect: $Z = 2.22$, $P = 0.03$

b Retromuscular mesh

| Reference | Seroma | | Weight (%) | Risk ratio |
	Mesh	Suture		
Strzelczyk *et al.*[7]	5 of 36	4 of 38	35·1	1·32 (0·38, 4·53)
Bevis *et al.*[8]	2 of 37	0 of 43	5·9	5·79 (0·29, 116·89)
Muysoms *et al.*[11]	2 of 56	0 of 58	5·9	5·18 (0·25, 105·47)
Jairam *et al.*[23]	13 of 185	5 of 107	53·1	1·50 (0·55, 4·10)
Total	22 of 314	9 of 246	100·0	1·67 (0·81, 3·47)

Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 1.41$, 3 d.f., $P = 0.70$; $I^2 = 0\%$
Test for overall effect: $Z = 1.38$, $P = 0.17$

a Data from studies using onlay mesh reinforcement; **b** data from studies using retromuscular mesh reinforcement. A Mantel–Haenszel random-effects model was used for meta-analysis. Risk ratios are shown with 95 per cent confidence intervals.

biological meshes, and one[5] used a rapidly absorbable intraperitoneal mesh.

Outcome measurements

The primary outcome was the incidence of IH after follow-up of at least 12 months. Twelve RCTs were included in the overall quantitative analysis for the primary outcome and publication bias[33] was evaluated. The meta-analysis showed a significant reduction of IH in patients with PMR compared with that in patients who had a primary suture (RR 0·35; $P < 0.001$) (*Fig. 2a*). The funnel plot was slightly asymmetrical, indicating a possible publication bias for studies favouring mesh prophylaxis (*Fig. 3*). Analysis of the primary outcome for studies with a low risk of bias (6 RCTs) showed that the occurrence of IH was significantly lower (RR 0·23; $P < 0.001$) in the PMR group than in the primary suture group (*Fig. 2b*). Both onlay and
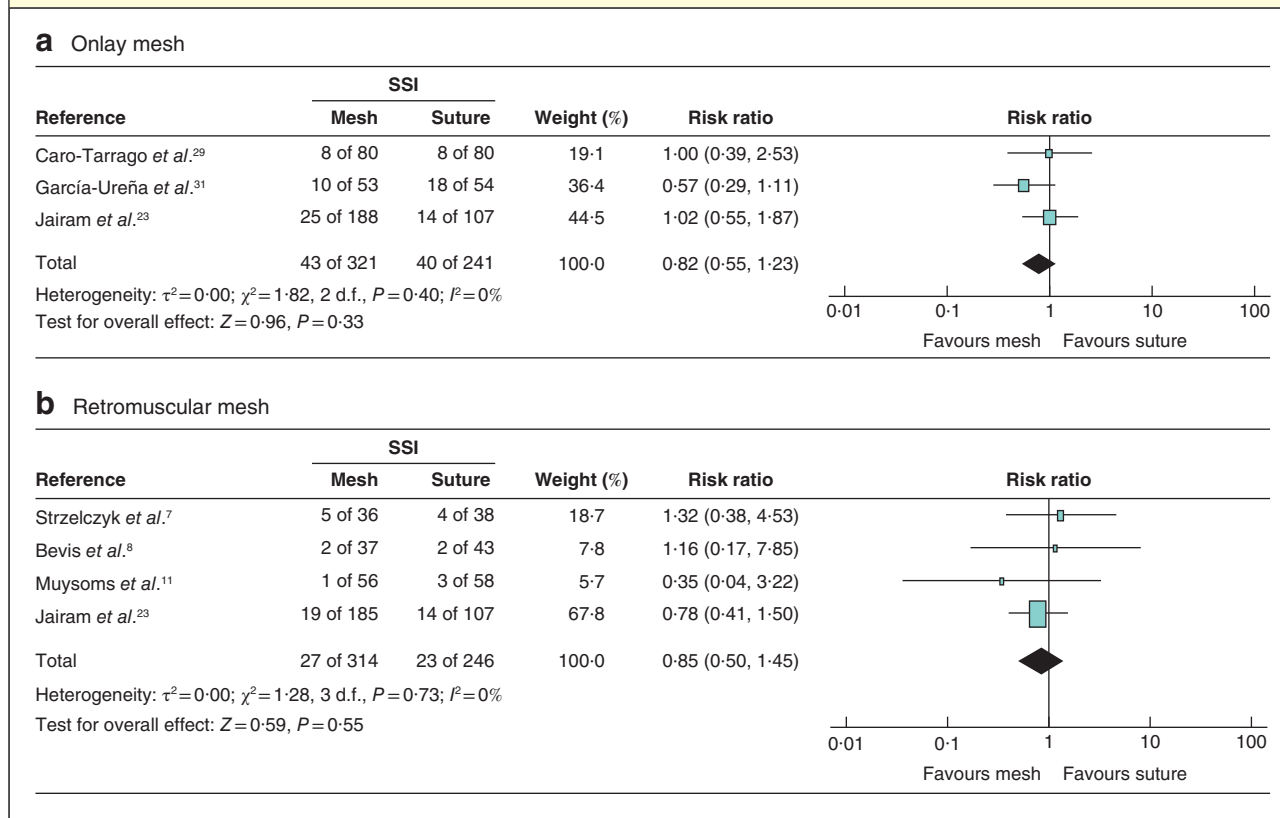
retromuscular PMR led to a significant reduction of the IH incidence compared with primary suture, with RRs of 0·26 ($P = 0.005$) and 0·28 ($P = 0.02$) respectively (*Fig. 4*).

TSA (for the primary outcome) was done for all 12 included studies. The CER proportion was 28 per cent, the RRR was 65 per cent, and a constant continuity adjustment was set at 0·5 events per group. The accrued information size ($n = 1815$) was 273·3 per cent of the estimated RIS ($n = 664$). This means that firm evidence was available. For low-risk-of-bias studies (6 RCTs), the CER proportion was 31 per cent and RRR 77 per cent. The accrued information size ($n = 1015$) was 283·5 per cent of the estimated RIS ($n = 358$) (*Fig. 5*).

Secondary outcomes were analysed for the low-risk-of-bias studies (6 RCTs). Patients with an onlay PMR had a higher risk of developing seroma (RR 2·23; $P = 0.030$) compared with patients who had a primary suture. Patients who had a retromuscular PMR had no

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Fig. 7 Forest plots of surgical-site infection after prophylactic mesh reinforcement of a midline laparotomy *versus* primary suture

a Onlay mesh

	SSI				
Reference	Mesh	Suture	Weight (%)	Risk ratio	Risk ratio
Caro-Tarrago et al.[29]	8 of 80	8 of 80	19·1	1·00 (0·39, 2·53)	
García-Ureña et al.[31]	10 of 53	18 of 54	36·4	0·57 (0·29, 1·11)	
Jairam et al.[23]	25 of 188	14 of 107	44·5	1·02 (0·55, 1·87)	
Total	43 of 321	40 of 241	100·0	0·82 (0·55, 1·23)	

Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 1.82$, 2 d.f., $P = 0.40$; $I^2 = 0\%$
Test for overall effect: $Z = 0.96$, $P = 0.33$

0·01   0·1   1   10   100
Favours mesh   Favours suture

b Retromuscular mesh

	SSI				
Reference	Mesh	Suture	Weight (%)	Risk ratio	Risk ratio
Strzelczyk et al.[7]	5 of 36	4 of 38	18·7	1·32 (0·38, 4·53)	
Bevis et al.[8]	2 of 37	2 of 43	7·8	1·16 (0·17, 7·85)	
Muysoms et al.[11]	1 of 56	3 of 58	5·7	0·35 (0·04, 3·22)	
Jairam et al.[23]	19 of 185	14 of 107	67·8	0·78 (0·41, 1·50)	
Total	27 of 314	23 of 246	100·0	0·85 (0·50, 1·45)	

Heterogeneity: $\tau^2 = 0.00$; $\chi^2 = 1.28$, 3 d.f., $P = 0.73$; $I^2 = 0\%$
Test for overall effect: $Z = 0.59$, $P = 0.55$

0·01   0·1   1   10   100
Favours mesh   Favours suture

a Data from studies using onlay mesh reinforcement; **b** data from studies using retromuscular mesh reinforcement. A Mantel–Haenszel random-effects model was used for meta-analysis. Risk ratios are shown with 95 per cent confidence intervals. SSI, surgical-site infection.

greater chance of developing seroma than those with a primary suture (RR 1·67; $P = 0.17$) (*Fig. 6*). The occurrence of SSI was not significantly higher for onlay PMR (RR 0·82; $P = 0.33$) or retromuscular PMR (RR 0·85; $P = 0.55$) than for primary suture (*Fig. 7*). There were insufficient data to analyse the incidence of haematoma and burst abdomen.

Discussion

This meta-analysis has shown that the use of PMR in patients undergoing midline laparotomy leads to a significantly lower occurrence of IH compared with a primary suture closure, with TSA indicating that the evidence was firm. This significant effect was shown for both onlay and retromuscular PMR. PMR was found to be safe, with no increase in SSI, but an increased risk of seroma formation for onlay PMR only.

This meta-analysis has a few limitations. Substantial statistical heterogeneity was seen in the studies regarding the primary outcome ($I^2 = 71$ per cent). This probably reflects the variability of surgical technique and methodological approach across studies.

Although the technique of PMR in the treatment arm of the RCTs is often well described, there is less information on the control group undergoing primary suture. Protocols often describe the use of a suture : wound length ratio (SL : WL) greater than 4 : 1, but data for the SL : WL ratio were recorded and reported in only a few studies[11], so that adherence to the optimal primary suture technique was unclear in most studies. Moreover, the short-stitch technique, which is currently considered the best evidenced technique with the lowest incidence of IH[3], was not used in any of the RCTs in this meta-analysis. Therefore, it could be argued that the treatment effect of PMR is increased because of a suboptimal suturing technique in the control groups.

Of the 12 RCTs included in this meta-analysis, half were considered to have a high risk of bias. Owing to the use of sensitivity analysis, however, the treatment effect was maintained, and was even greater when only studies with a low risk of bias were analysed.

Only RCTs with a minimum follow-up of 12 months were included in the meta-analysis, with all but one[29] having follow-up of at least 24 months. This is still too short, however, to evaluate the long-term efficacy or potential late adverse effects of PMR.

In most studies, physical examination was used to detect IH during follow-up. Some added selective or systematic medical imaging for the evaluation of IH, using either ultrasound imaging or CT. Imaging will increase the number of patients diagnosed with IH by detection of subclinical IHs, and this might overestimate the importance of PMR in providing clinical benefit.

Most of the 12 included studies used a polypropylene mesh in either an onlay or a retromuscular position; two[10,30] used a biological mesh and one[5] used an absorbable synthetic mesh. Two of these studies did not show PMR to be effective, and all three were considered to have a high risk of bias. All studies with a low risk of bias used either an onlay or a retromuscular mesh position, and all included trials were performed in an elective surgery setting. The results of this meta-analysis on PMR can therefore be considered valid only for synthetic, non-absorbable mesh in either an onlay or a retromuscular position in an elective setting.

The slightly asymmetrical funnel plot for IH indicates possible publication bias towards studies that favour PMR, resulting in an overestimation of the underlying beneficial effect of the intervention.

Most studies included only patients considered at high risk for developing an IH. It is difficult to identify the individual risk factors whereby patients would benefit from PMR. The guidelines on the closure of abdominal wall incisions from the EHS[19] state that the evidence is weak for the use of PMR in patients at high risk of IH development. Such a guideline could be implemented only if the EHS Guidelines Development Group also described the exact criteria for considering patients to be at high risk. From this perspective, the study performed by Fischer *et al.*[18] is interesting, as these authors stratified patients into four IH risk groups (low, moderate, high, extreme), based on characteristics of the patient and the surgical procedure. From this meta-analysis, it seems clear that patients undergoing AAA repair and those having bariatric surgery through a midline incision will benefit from PMR, although these are now less common as many patients with an AAA are treated with endovascular procedures, and bariatric surgery is often performed by a laparoscopic approach.

Selection based on patient characteristics needs cut-off values. The appropriate cut-off value for BMI is unclear. The PRIMA trial[23] used a BMI of at least 27 kg/m² as an inclusion criterion for PMR, but further research is needed to identify an appropriate BMI cut-off point at which the risk of developing IH increases. Data from large clinically oriented prospective registries[34] might be helpful to explore which factors might lead to an increased risk of IH.

PMR can be considered safe for elective laparotomy. The only adverse event detected in this meta-analysis was an increased rate of seroma formation after onlay PMR, related to the subcutaneous dissection required. However, even though the occurrence of seroma was higher in the onlay PMR group, there was no increase in SSI. There were insufficient data to analyse the number of other adverse events, such as haematoma or burst abdomen.

One of the main strengths of this meta-analysis is the fact that RCTs with a low risk of bias were analysed separately[35]. Further, the most up-to-date RCTs were included[23]. TSA showed firm evidence in favour of PMR for midline laparotomy in high-risk patients, suggesting that no further trials are required to address the effects of PMR in this population. RCTs in other patient populations with differing levels of risk would, however, be helpful to evaluate the effectiveness of PMR.

Laparotomies are performed by a variety of surgical specialties, such as vascular surgeons, colorectal surgeons, gynaecologists and urologists. Many of those surgeons have little experience in treating abdominal wall hernias with mesh, particularly for retromuscular mesh placement. This meta-analysis has shown that onlay PMR, which is easier to perform, is also effective, and likely to be more acceptable to these surgeons.

This meta-analysis has provided evidence in favour of closure of midline laparotomies with PMR in high-risk patients. Individual risk factors should be taken into account to select patients who will benefit (most) from PMR, which should become standard treatment for high-risk groups.

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Supporting information

Additional supporting information can be found online in the Supporting Information section at the end of the article.